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LARGE-ARRAY SIGNAL AND NOISE ANALYSIS

Quarterly Report No. 8

1 April 1968 through 30 June 1968

Frank H. Binder, Program Manager

TEXAS INSTRUMENTS INCORPORATED
Science Services Division
P.O. Box 5621
Dallas, Texas 75222

Contract No. AF 33(657)-16678

Prepared for

AIR FORCE TECHNICAL APPLICATIONS CENTER, attn: VSC
Washington, D.C. 20333

Sponsored by

ADVANCED RESEARCH PROJECTS AGENCY
ARPA Order No. 599
AFTAC Project No. VT/6707

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INCORPORATED
SCIENCE SERVICES DIVISION

12 July 1968

Air Force Technical Applications Center
VELA Seismological Center
Headquarters, USAF
Washington, D.C. 20333

Attention: Major Carroll F. Lam

Subject: Eighth Quarterly Report Covering Period April 1, 1968 Through June 30, 1968

AFTAC Project No.:	VT/6707
Project Title:	Large Array Signal and Noise Analysis
ARPA Order No.:	599
Name of Contractor:	Texas Instruments Incorporated
Date of Contract:	16 May 1966
Amount of Contract:	$1,083,696
Contract Number:	AF33(657)-16678
Contract Expiration Date:	25 June 1968
Name and Phone No. of Program Manager:	Frank H. Binder Area Code 214, 238-3473

Gentlemen:

Below is set forth a summary of work progress during the previous quarter.

PUBLICATION OF SPECIAL REPORTS

The following special reports have been published during the past quarter.

LASA Special Report No. 16 - ITERATIVE TECHNIQUES FOR THE SOLUTION OF FREQUENCY-DOMAIN FILTER SETS

LASA Special Report No. 18 - K-LINE SPECTRAL ANALYSIS OF LASA SHORT-PERIOD SUMMER NOISE

LONG PERIOD SUMMER NOISE STUDY

Analysis of eight 80-minute noise samples, recorded during the period 29 March to 7 October 1967, has been completed. Four of these samples were recorded consecutively thereby forming a 320 minute long noise sample. The analysis includes power density spectra, multiple coherencies, and wavenumber spectra. In general, the summer noise appears similar in character to previously analyzed winter noise samples.

The power density spectra typically show a large peak at 0.05 to 0.07 Hz, a smaller peak between 0.11 and 0.14 Hz, and an occasional peak near 0.025 Hz. Multiple coherencies are high in the 0.05 to 0.07 Hz and 0.11 to 0.13 Hz regions. A large portion of the 0.05 to 0.07 Hz noise propagates at surface wave velocities. In most cases the direction of propagation agrees fairly well with the azimuth of storm centers.

Comparison of the RMS values of the various noise samples indicates that the level of the summer noise is significantly lower than that of the winter noise. One unusual feature of the long noise sample is the predominance of bodywave energy coming from the north at 0.13 Hz.

The only usable microbarographic data was recorded by an instrument located within 50 feet of the Ao sensor and simultaneous with the 320 minute long noise sample. As expected, the power density of the pressure decays exponentially with increasing frequency. No significant coherence was found between the pressure and the Ao vertical seismometer output. Unfortunately, the Ao horizontal data recorded at this time is very poor and could not be used.

LONG PERIOD SIGNAL ANALYSIS AND DISSECTION

A display of the surface modes on all vertical traces and the rotated horizontal traces for a total of 10 events has been prepared. This data indicates the type of channel to channel signal differences which are encountered. For some of the more dissimilar (sensor to sensor) events beam steers have been calculated using the entire array, Ao, E, and F rings; Ao, C, and D rings for all three components.

A visual analysis and an interpretation of the implications of this data is being completed. A report covering the above data should be forthcoming in a few weeks.

A compound event, synthesized from events from New Hebrides (azimuth 257.5°) and Hokkaido (azimuth (312°), has been processed through multichannel filter systems designed as follows:

- Theoretical (dispersive plane wave) signal and noise models using Ao and C ring designed to pass the New Hebrides event

- Theoretical (dispersive plane wave) signal and noise model using Ao and E ring designed to pass the New Hebrides event

- Theoretical (dispersive plane wave) signal and measured compound event noise using Ao and C ring designed to pass the New Hebrides event

The SNR of the unprocessed compound event is approximately 0. Signal distortion, while not severe in any case, was more noticeable in the case of the E ring filters. The two sets of C ring filters appeared to suppress the interfering event equally well. The SNR gain is estimated to be roughly 15 db. Suppression of the interfering event by the E ring filters was poor, particularly in the later portion of the Rayleigh wave. Wavenumber responses of the E ring filter set were obtained at 0.03, 0.05, and 0.07 Hz. At 0.07 Hz the reject region in wavenumber space becomes very small. It is possible that the noise model and the actual interfering event differ sufficiently so that the filter reject region misses the noise. Since the two C ring designs indicate no apparent advantage of the completely theoretical design, and since the E ring filter set indicates a possible disadvantage of this type of design, future filters will be designed using a theoretical signal and measured noise.

To check beamsteer performance, the Hokkaido event was summed after applying the New Hebrides time shifts. This was done for four different sensor combinations; Ao and C ring, Ao and E ring, Ao, C, and E ring, and LASA less two anomalous traces. The poorest of these, the Ao and C ring combination, resulted in almost no attenuation of the Hokkaido event. The best, the Ao and E ring combination, was inferior to the C ring MCF's by as much as 10 db.

A second compound event has been synthesized from the Hokkaido (azimuth 312°) and Mongolia (azimuth 340°) events. Five channel

MCF's employing the Ao and C ring, and Ao and E ring sensors have been designed and are under evaluation. Based on these results, filters will be designed for other appropriate sensor combinations.

LONG PERIOD RAYLEIGH WAVE SIGNAL EXTRACTION FROM AMBIENT NOISE

This work was undertaken to evaluate the relative performance of multichannel signal extraction filters and beam steer processors in extracting long period Rayleigh phases from ambient noise using various array geometries. Due to a lack of adequate noise samples in time proximinity to events in our library, it was necessary to imbed scaled, relatively strong, signals in selected winter noise samples. Multichannel filters were designed from the noise statistics and the azimuth of the event. Both non-dispersive and dispersive signal models were generated, the latter using the LASA north dispersion curve.

To date, three general cases have been studied. These are:

- A noise sample dominated by a point-like source [(04:17:00.5 - 05:36:59.9) Dec. 3, 1966] and a signal widely separated azimuthally from the noise source [(azimuth 254.7°) California event]

- A noise sample dominated by a point-like source [(20:34:02.4 - 21:54:01.8) Feb. 7, 1967] and a signal with near the same azimuth [(azimuth 312°) Hokkaido event]

- A relatively homogeneous noise field [(13:02:01.6 - 14:22:01.0) Dec. 13, 1966] and a typical signal [(azimuth 257.5°) New Hebrides event]

The processing schemes have used various combinations of the Ao, C, D, and E ring vertical seismometers. To facilitate the determination of noise reduction and signal preservation, the processors have been applied separately to the noise and signal samples. Prior to filter design and processing, the noise and signal were re-sampled to a 2-sec sampling interval. Although the experiments are not yet complete, results obtained thus far support the following conclusions:

- For point-like noise sources with near surface

wave velocity, the signal-to-noise ratio gain is a function of azimuthal separation of signal and noise, being least for small separations

- Multichannel filters outperform simple beam-steers in noise reduction. The degree of improvement is strongly dependent on the characteristics of the noise field

- For small diameter arrays (D ring or smaller) there is no significant difference between results obtained using a non-dispersive model and those obtained using a dispersive model

HIGH-RESOLUTION FREQUENCY-WAVENUMBER SPECTRA: EVENT PROCESSING

Five short period events having magnitudes ranging from about 4.4 to 4.8 and three long period events compounded at three amplitude ratios (2/1, 5/1, and 10/1) from a Greenland and a California event were processed. Spectral types consisted of high-resolution technique variations and conventional frequency-wavenumber spectra.

A. PROCESSING DESCRIPTION

A 40 second time gate was initially used for the short period data but this was reduced to 15 seconds for the LASA A-D rings array, 10 seconds for the extended E3 array, and 5 seconds for the F1 subarray to improve the time gate signal-to-noise ratios. Frequency-wavenumber plots were made at frequencies of .850, 1.000, 1.150, and at the peak frequency of the time gate from the center seismometer of the array. The fixed frequencies approximately spanned the region of short period energy for P-phase teleseisms.

The long period compound events were processed using a 330 second gate starting at the beginning of the weaker Greenland event. All 21 LASA long period channels were used. Frequency-wavenumber plots were generated at .04 Hz which was near the peak frequency for both constituents of the compound events.

B. PROCESSING CONCLUSIONS

Conventional and high-resolution frequency-wavenumber spectra, computed at a single frequency, give the best epicenter location at the peak frequency of the single trace power spectra (data has been bandpass filtered). Preselection of three fixed frequencies does not give consistent epicenter location. The apparent epicenter varies as a function of frequency.

A velocity preserving stack over the three preselected frequencies gives the most consistent epicenter location. Advantage is taken of relative maxima in the frequency-wavenumber plots.

Conventional frequency-wavenumber spectra give as good or better epicenter location than high-resolution frequency-wavenumber spectra using the center seismometer or the outer ring as reference. Spectra of the long-period events indicate that high-resolution frequency-wavenumber spectra are more sensitive to the signal-to-noise ratios of the time data than conventional spectra. Event location degrades rapidly as the signal-to-noise ratio of the time traces decreases.

LOCATION STATISTICS

The study undertaken to determine how event location using wavenumber spectra is related to the signal-to-noise ratio of the data has been divided into two experiments. The first experiment, which utilized an uncorrelated noise field, has been completed. The second experiment uses correlated noise fields with processing at the subarray level.

A noise power spectral matrix, N, is generated from selected combinations of disk, annulus, and multiple plane wave noise models. To this matrix is added the power spectral matrix of a plane wave signal to form the assumed data power spectral matrix. One hundred complex noise vectors are formed from the output of a normal (mean = zero, variance = one) random number generator. The vectors are transformed to correlated noise transform vectors each having the spectral matrix N. To these vectors is added a scaled plane wave signal transform vector. These data are then processed using a LASA standard subarray geometry. Output of the computer program is normalized mean and standard deviation for the probabilistic, the high-resolution and the conventional techniques.

The program has been run using a disk noise model and an

infinite velocity signal. Other noise models representative of those encountered with real data are planned.

Very truly yours,

TEXAS INSTRUMENTS INCORPORATED

Leo Heiting
Assistant Program Manager

LH:se

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13. ABSTRACT

This report is a summary of results obtained on Contract AF 33(657)-16678, LASA Evaluation, during the period 1 April 1968 through 30 June 1968.

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